The Study of the Application of a Computer to Production Control

by D. C. Hemy and W. J. Kease*

Summary: This paper reviews the possible application of an electronic digital computer to production and material control routines. The paper is divided into four parts: (1) a review of production control systems; (2) a discussion of the characteristics of a digital computer capable of functioning on production control work; (3) an outline of a system of material control; and (4) an outline of a system of production control, using a digital computer. In the appendix, detailed consideration is given to some of the calculations and references which have to be made in translating a proposed production programme into manufacturing and material delivery schedules.

1 PRODUCTION CONTROL SYSTEMS

1.1 *Introduction*

The field of production control is large and in this paper we shall confine our considerations to techniques associated with engineering manufacture. Even here a diversity of application occurs from one company to another, since market conditions, the nature of the product and processing methods all impose limitations which make each control system unique. None the less, there are a number of basic requirements which must be satisfied, and before proceeding with the manner in which electronic digital computers may be used in this field, it is proposed to outline what these requirements are.

Production control systems are designed as service mechanisms to assist in the translation of production policies into action, and only if a firm such policy exists in a company can the control system be effective. The system itself must be able to initiate certain actions, subsequently appraise them for divergence and, ultimately, indicate such corrective action as may be necessary. This substantially means the ability to develop a comprehensive production plan and to translate this plan into the necessary action primarily through the processing of control information.

From the production control point of view, and assuming basic production engineering and personnel considerations to be satisfied, the development of a realistic production plan will depend on an accurate assessment of plant capacity and material requirements. The development of the plan and its effectiveness in operation will depend upon whether valid information is conveyed in accurate symbols at the required rate. Before proceeding to outline the nature of these data it is useful to review the work which production control performs down to the completion of the final product.

1.2 *The Production Control Routine*

To simplify considerably, the initial action in the production control routine is to examine the proposed product to ascertain if there is any "key" processing operation, which is likely to control the rate at which the product can be manufactured. If there is, this may be conveniently located on a time schedule to give an indication of when production can reasonably commence. The next action is to examine the proposal to discover if it contains any key material which has unusual physical characteristics, or which, for this or any other reason, is difficult to obtain, and thus similarly likely to control when manufacture of the proposed item can begin. In the first case it may be reasonable to reserve the key capacity, and in the second to give selected suppliers advance information with regard to key materials.

With a knowledge of these limiting factors, the production control department can begin to build up the production plan, to co-ordinate the activities of the design department, production engineering and auxiliary services, to the end that all designs, specifications, foundry patterns, dies, tooling equipment and the like are available as required. Estimates of overall plant loading to utilize fully the production capacity of the factory may also be prepared so that, as a design or section of a design is released, materials may be ordered, or, in the case of previously assessed key materials, confirmed, and more detailed work loads estimated. From the foregoing, work schedules showing any subcontracting can be prepared and, eventually, delivery schedules calculated. From this point, the main monitoring routine may commence. This will be discussed later.

1.3 *Basic Data Standards*

It is obvious from the foregoing that a knowledge of what constitutes the product to be manufactured is fundamental to a production control system. Generally speaking, this means a knowledge of the materials, processes and time relationships which give each product its unique identity. The processes through which articles pass, during their transformation into a predefined saleable state, are equally as important as the materials constituting them and the time durations and relationships of each production stage, although it must be appreciated that the last has two degrees of significance. During production engineering and preplanning stages, a certain amount of time is established for each process such as drilling, milling, welding, etc.;

* Mr. Kease is now with A.E.I.—Hotpoint Ltd.

these may be called the times as "planned." The other significance of "time" relates to the available production capacity, and is very important when a production schedule is being drawn up. The available production capacity plotted on a time-base obviously imposes limits on what can be produced, irrespective of the planned times mentioned.

1.3.1 *Times and Sizes*

It has already been stated that in this paper we are concerned with the techniques of engineering manufacture, and these divide roughly into three categories: the mass production type, normally with flow characteristics, batch production and order production. The majority of companies are concerned with one or a mixture of the last two varieties, which imply either production at established rates in anticipation of sales founded on long-term plans, or work undertaken to satisfy the needs of individual orders each of which requires an exclusive plan. Mass production will not, therefore, be further considered, although this must not be taken as implying that computer-assisted techniques are inapplicable to the mass production situation.

In general the time relationship between the pieces of the product as planned must be established, precisely or approximately, before production can reasonably commence. The relationships are:

1. The throughput time for each piece or assembly involved.
2. The minimum lead-time for each piece or assembly (see Appendix).
3. The minimum ordering period for material.
4. The minimum delivery cycle for material.

Throughput times and lead-times may be established on the basis of time-study/rate-fixing procedures for repetition batches, or work estimates for one-time quantities. In the case of order production the size of both the processing and purchasing batches will, naturally, be conditioned by the size of the order, but in the case of repetition work two further items of data are required:

5. The minimum economic processing batch size.
6. The minimum economic purchasing batch size.

The former is established on the basis of keeping plant resets to a minimum, allowing adequate capacity for other work, and producing a reasonable quantity of the specified component at a time. Quite often the latter—the purchasing batch size—will coincide with the processing batch size; on occasion, criteria established by the supplier or minimum/maximum stock requirement will determine the quantity. If there is a special unit of purchase, such as the gross (144), this too, must be allowed for.

The six factors mentioned are shown as they affect a production situation; in the Appendix a detailed explanation is given. The materials or parts making up an assembly must be clearly identified as to type and assembly stage. The material constituting a component piece-part must be stated after necessary allowance has been made for set-up quantity, chucking length, and parting-off requirements, etc. So far as some material—particularly strip and sheet—is concerned, the economics of manufacture make it desirable that the quantity required be expressed in such ways as "so much makes ten," waste by off-cuts being thereby kept to a minimum.

1.3.2 *Alternative Materials and Processes*

For certain piece-parts, the material specified for use is not unique and, if necessary, alternative specifications may be used to maintain production. The number of materials considered as suitable alternatives in a given situation will always be limited by one or a combination of:

1. Physical suitability.
2. Ability to process.
3. Economic feasibility.

Physical suitability may be determined by allowing a material of the same metallurgical or chemical characteristics but of different dimensions to be used, or of different broad physical properties to be employed, provided such precise requirements as specified tensile strength and ductility are satisfied. Ability to process will be limited by the plant available, and economic feasibility by the desire to manufacture at a determined price.

An alternative process may arise from the consideration of two quite distinct sets of data. It may be necessitated by the demands of alternative material or from the desire to use alternative plant, such as key seater/small vertical miller, to give added flexibility in the execution of the production program. In many cases details of alternative materials and processes can be included with certainty in the basic data for each item, rendering expensive consultation with the technical departments unnecessary.

1.4 *Material Schedule*

The development of a detailed production plan depends, at one point or another, on an analysis of the product in terms of materials and time, using the data outlined in the previous section. Such an analysis yields a schedule of material requirements as shown in Stage 2 of Fig. 4, in the Appendix. Such a schedule is a statement of the way in which material should be delivered, if it were needed to match the output assembly program.

1.4.1 *Requirements Schedule*

Purchasing orders may be placed on the basis of this schedule, it being a most useful guide to the manufacturing company's buyers as a basis for negotiation with suppliers. Deliveries are not in all cases made strictly in accordance with it, however, there being several other factors which have to be taken into account before a delivery schedule is achieved. Perhaps the most obvious example of these factors occurs when an order is placed on more than one supplier for the same material in the same production period.

Given that a list of approved suppliers exists, and is maintained as new suppliers are sanctioned, the most important thing mentioned as mandatory for the calculation of the best delivery schedule is a knowledge of the rate at which the material is likely to be absorbed by the main processing departments. Two further important data are the delivery cycles, which have already been mentioned and, where applicable, the minimum delivery quantities.

1.4.2 *Delivery Schedule*

In practice, the material delivery schedule can often depend on the main processing schedule which, from a consideration of the time cycles involved, is sometimes very different from the output assembly program, particularly if batch processing techniques are employed. The implication is that in the batch production situation, ideally, plant loading should be effected before a delivery schedule can be calculated to produce the most worthwhile result. For such repetitive production, the conditions imposed by the batch load on the production departments should be observed, together with the delivery conditions established by the supplier or suppliers. These produce a fairly complicated result as illustrated in Stages 3 and 4 of Fig. 4, in the Appendix.

In the order production environment the compilation of a delivery schedule is much more straightforward, and may, in certain circumstances, be a simple restatement of the requirements schedule. Ideally, again, process loading should be effected before the delivery schedule is finalized, but this precedence does not appear to be so critical as in the case of repetitive production.

1.4.3 *Minimax Techniques*

One final factor has a bearing on material scheduling, the need to observe any minimum/maximum stock regulations which may be in force. Minimax techniques may be employed, where there is a desire to create a working reserve against incompletely defined production situations, without at the same time investing too much capital in material stocks or risking surplus holdings. Again, such techniques may be used to gain a smooth input of material against spasmodic output. In both cases scheduling is not perceptibly complicated by the use of minimax levels, although these must, to be most effective, be established on the basis of future rather than past needs, and must be continuously monitored.

1.5 *Process Loading and Scheduling*

The loading of the processing plant and the scheduling of work on to it have already been referred to, it being suggested that overall work loads may be estimated fairly early in the production control routine, whilst detailed loading, or scheduling, follows later. The object of the overall loading procedure is to ensure that, generally speaking, the balance of plant is satisfactory and there are no undue over- or under-loads. The overall load can be calculated from a pre-established knowledge of the "processing content" of each product in terms of known plant availability. Alternatively it can be calculated or estimated afresh as each production programme is planned.

The more detailed load on the processing plant is produced by scheduling the individual operations to be performed on each component item in relation to the plant capacity. The starting and finishing dates for each operation on each batch of work should be established, and as this is done the capacity outstanding is reduced. Appropriate documentation for control may be produced at this stage, or at a later stage as is discussed in Part 4.

1.6 *Monitoring*

During the translation of the production plan into action, the production control system must be capable of inspecting all points where deviations are likely to occur; in practice, this means every stage of production from initiation of designs to delivery of finished product. The release of drawings from the design office and the urging of requisitions on the buying departments must be monitored, and, from the materials aspect, receipts and issues must be recorded continuously so that an up-to-date stock position is readily available. Work-in-progress in the processing departments must be monitored, either operation by operation or at key processing points, to enable checks to be made to ensure that existing plans are being executed, and information to be provided for new plans to be formulated. Particularly important in the former case is the testing of issues and receipts against schedules, and the noting of quantities above or below expected levels, together with records of scrap or rejected materials encountered.

A further important monitoring procedure concerns the introduction of design changes into a production plan. Alterations in design, however classified, inevitably bring problems regarding change-points and balanced sets of stock, and it is imperative that the requirements of each design alteration are carefully monitored, so that they may be effectively realized.

1.7 *Conclusions*

Having presented this review it will be obvious that important disciplines have to be imposed on all areas of production control if the "system" is to function effectively. It is now proposed to discuss the characteristics of a digital computer capable of functioning in the production control field, to outline two systems relating to production control, and to show how the requirements already described may be satisfied for the two systems using electronic data-processing techniques.

2 Digital Computers

2.1 *Computer Characteristics*

Many attempts have been made, over the last few years, to find an easy way of comparing computers, and numerous tabulations have been drawn up giving

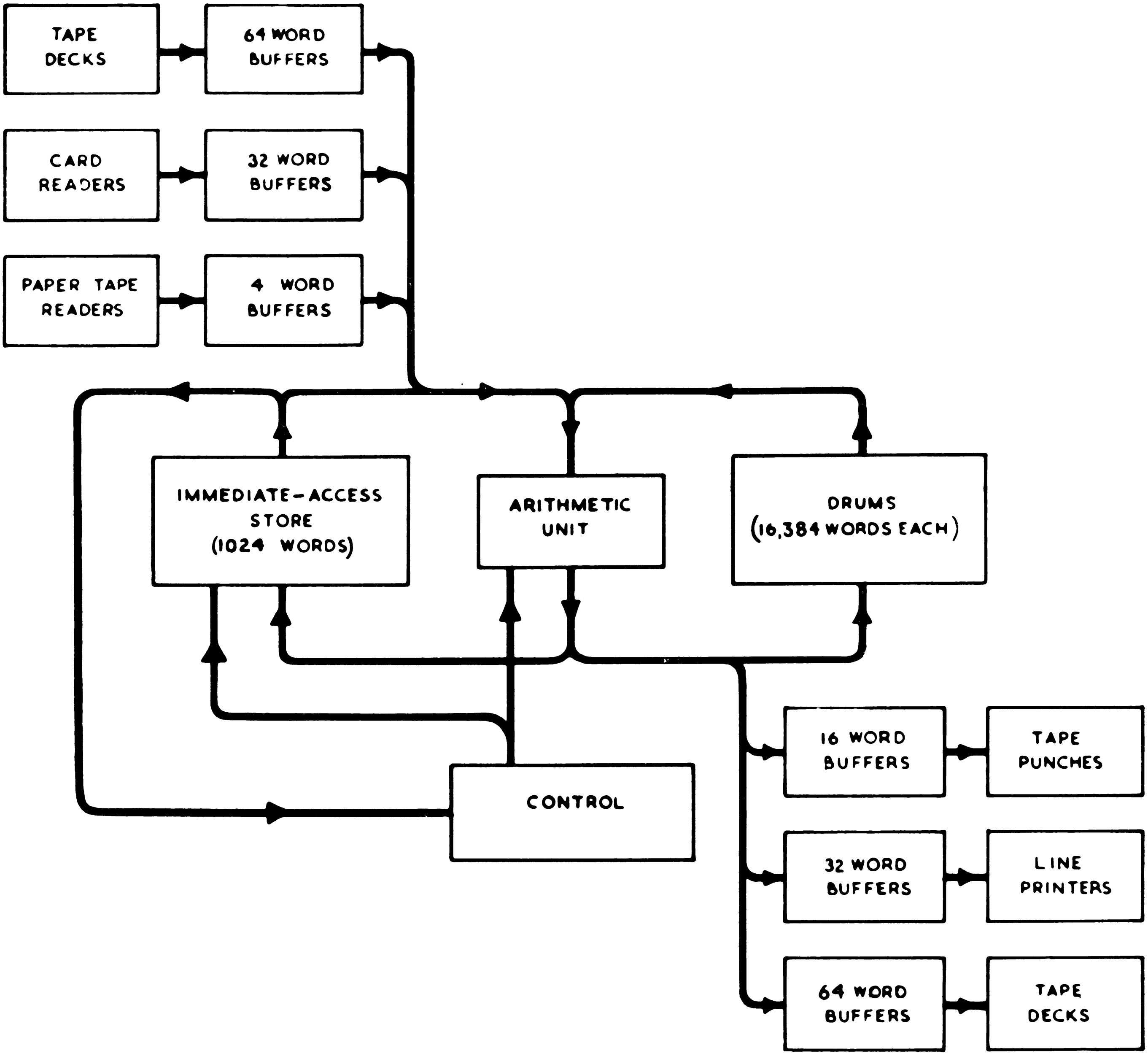

FIG. 1.—Block diagram of EMIDEC 1100 computer.

certain selected, or all possible, details of the various machines available. Such digests of information are undeniably of value, but in so far as they are regarded as a means of ranking computers, they must always fail, since a digital computer is, in almost all cases, to a greater or lesser degree a general-purpose machine, and its power and suitability in a particular instance can only be judged in relation to the application for which it is intended. However, although it is not possible to arrive at any absolute measure of a computer's capabilities, it is obvious that such an assessment must at times be attempted in general terms. It is proposed, therefore, to examine the characteristics which are of prime importance in such an assessment, and then to consider their particular relevance to production control applications.

It may be thought that some factors have been omitted, and others given too great prominence; for particular applications that may be so. General experience over more than ten years has, however, confirmed the following as the characteristics of greatest general significance.

2.1.1 *Computing Speed*

It is necessary when considering speed to make a distinction between *computing speed* and *overall operational speed.* The latter is clearly most complex, and can be estimated only in relation to a particular application; in fact, it comes close to being a general assessment of the computing system as a whole. Computing speed may be taken to mean the speed of arithmetic and logical processing within the computing centre itself. Even here no absolute measure can be applied, but a reasonably close assessment can be made by reference to easily distinguishable criteria: the time taken by the various arithmetic and logical instructions in the order code. Normally such a measure is only approximate, not only because of the variations from machine to machine of the relative times for different functions, but more because the computing efficiency is heavily influenced by the type of order code. Thus a two-address machine with the same add time as another one-address machine will be considerably faster in that respect.

In theory, some overall index could be produced by weighing the individual function times by their expected frequency. Unfortunately, although for a given machine one may get surprisingly constant frequency figures for the various functions on a wide range of applications, these frequencies will be affected from machine to machine by the general range of facilities provided. Thus, in the end, the assessment can be made only in very general terms.

2.1.2 *Input-Output Facilities*

The development of commercial computers from mathematical computers soon brought the realization that commercial work is distinguished by the large volume of information to be put into and received from the machine, and that, if the work was to be done efficiently, high operating speeds were necessary. In fact this was for some time over-emphasized to the extent of neglecting a proper balance. It remains true, however, that the point is of crucial importance, since it will be found in practically any application that the system is at some points limited by the input/output facilities.

Speed alone, however, is not sufficient, since it is the input and output ends of the computer system that have a direct effect on the external world, and here more than anywhere flexibility is required. Thus data preparation costs are normally a very significant part of the total cost of a computer system, and it is important to select the correct medium. In practice, at present, this implies punched cards or punched tape, each of which offers advantages in particular circumstances. Either medium may be appropriate to a given system, or, in some cases, both, and the number and type of inputs should be capable of variation.

As regards output, too, a high degree of flexibility should be available. Perhaps the most argued point on this topic is the relative merits of on-line and off-line working; it is sometimes held to be a principle that off-line working is faster, but in fact there are many cases where no gain in overall speed is achieved by off-line working, and even a loss in clock time may occur. It is undeniable that in many applications a significant gain can be made by adopting off-line printing, but it is still the soundest course in planning a system first to assume on-line working (which must always be cheaper in initial capital outlay), and then to consider whether the additional capital cost of a change to off-line working is justified by the gain (if any) in computer speed. A computer system for commercial work should therefore allow for either arrangement, or, as is desirable in some cases, for both.

2.1.3 *Storage Capacity*

Storage capacity is, for present purposes, taken to mean the amount of random-access storage directly available to the computer, and leaves out of account (for separate consideration) such storage as is provided by magnetic tape, which is of a serial nature, and is not subjected to the same limitations on capacity.

The term "random-access" storage has through frequent and sometimes careless use become a term which is particularly difficult to define precisely; its general connotation, however, is sufficiently accepted not to require such definition here. It is evident that in any application it may be necessary to refer to stored information in a sequence differing from that by which it is ordered in the store. Thus it is an attribute of such storage that the time taken for reference to items shall not be conditioned by their stored sequence. This is not to say that all references to items in a given store will necessarily be made with the same speed, although the differences should not be such as to make the concept of an average access time meaningless. Still less is it implied that the storage in a given system will be homogeneous; it is a common feature of many systems that a relatively small proportion of the storage is characterized by low access time, whereas the bulk has a higher access time.

As regards capacity, however, irrespective of speed, which will be considered separately, two points need to be made here. First, for any normal commercial application, a reasonably large store is of considerable importance. If the program is to be comprehensive, then it must be measured in thousands of instructions: and if the store will not permit the use of programs of this length, then either the job will suffer from an artificial division into an unnecessary number of passes, and an increase in operating problems and costs, or many of the ramifications will have to be dealt with outside the computer, with a similar effect.

On the other hand, it is equally necessary to be cautious in accepting what at first appear to be cogent reasons for assuming that vast storage is necessary for the solution of a problem. A typical case arises in many inventory control applications, where it is claimed that information about any item of stock may be required at any time. Certainly such a requirement can be met by providing random-access storage sufficiently large to hold all items in the inventory. But the adoption of such a solution will generally spring from a failure first to establish the true and essential requirement of the work before seeking a solution. Although, undoubtedly, such a solution may in certain cases be right, in general a superficial acceptance of it can more usually be taken as a symptom of bad definition of the problem, and bad planning. Even where the requirement is real, it will be found to be only one requirement among many, and the only one requiring storage on such a scale. Before the necessity for such storage is adopted, it must be considered whether that one requirement justifies the costs involved. Nevertheless, while this is a very real danger to be guarded against, it is certainly true that, if a computing system is to be of general use, it should be capable of incorporating random-access storage of large range.

2.1.4 *Storage Speed*

While storage speed is undoubtedly a most significant factor, it is considerably more difficult to isolate its effect on computer efficiency. In the first place, it is a common feature of many computers that the storage is at more than one level: a certain capacity of rapid-access storage is provided, in some cases purely to enable computing to be effected more rapidly, in others to provide storage for both the information and program being worked on, so that the general operating speed of the system is considerably increased. It becomes uneconomical, however, to provide more than a certain amount of such storage (which may take a number of forms such as magnetic cores, or delay lines), and the bulk of the storage is provided by devices of lower speed, but correspondingly lower cost, such as magnetic drums. Clearly, a machine with drum storage will be slower operationally than a machine with comparable core storage but, provided the former has sufficient fast storage to give flexibility, the loss in speed will not be a serious disadvantage.

Thus an assessment of this factor will depend largely upon the view of the balance between high-speed, and lower-speed but larger storage. In fact, although it is of major importance, it cannot be judged to any really significant extent without considering particular applications. In general it may be said that, if the fastest storage is of sufficient size to accommodate both numbers and instructions being currently worked on (say, a capacity of 500 to 2,000 words) and of a speed consistent with satisfactory computing speed, then the remainder of the storage can be significantly slower, to the extent that access times of up to 50 milliseconds or more may be found to be adequate.

2.1.5 *Auxiliary Storage*

Assuming that we may reject the somewhat desperate expedient of providing sufficient random-access storage for all stored data which may occur, then auxiliary serial storage of some kind is necessary. Thus practically any computing system that is to handle a wide range of jobs successfully will provide for the use of magnetic-tape storage.

Although, as regards the planning of the job, there is a tendency to class magnetic tape as a storage device, there is much to be said for considering it rather as an input-output medium. It is fundamentally a serial device, and there is a great danger that unless this is continually borne in mind, attempts to mitigate its handicaps soon become costly and unprofitable efforts to convert it into a sort of direct-access storage. In fact, careful planning, with the object of exploiting its advantages, is far more profitable than efforts to increase its application in ways that do not accord with its fundamental properties. Magnetic tape provides a relatively cheap medium for simple serial storage, and as such has a place in practically any application. But it will be found that, when it is attempted to go beyond this, the complications involved will often seriously outweigh the minor advantages to be gained.

The two qualities which are fundamental are reliability and a good working speed. The former of these can of course, hardly be over-emphasized; the latter, on the other hand, must be viewed with some caution. Undoubtedly a low tape speed will have an adverse effect on computer operation, but a point is soon reached where, in many parts of an application, increasing tape speed brings little increase in overall speed.

2.1.6 *Flexibility*

In considering computers in relation to commercial applications, considerable emphasis must be placed on flexibility. Not only may an installation be required to handle a wide range of jobs, each with its own pattern and requirements, but it is inevitable that with time, and with broadening experience, these jobs will change, and will place new demands on the computers. Thus it is necessary to ensure not merely that an installation is sufficient for the current applications, but that it is capable of re-deployment to meet changes in the applications and, if necessary, that it can be easily extended to give it increased scope and power. Of course, in assessing such a characteristic, no sort of measure can be used; it is rather a question of being satisfied that the equipment is well-balanced, and thus does not impose undue restrictions in planning the jobs to be carried out.

2.1.7 *Simplicity*

This quality is probably the most significant, and yet the most neglected of all. A computer is essentially a complex instrument, and there has been a tendency to become resigned to more and more complexity in computers and computer applications. It is a commonplace of all systems planning that the best system is a simple system, and because of the inherent complexity of a computer as a machine, it is essential to bear this in mind. Moreover, since the computer system must be comprehensive, the system itself cannot be entirely simple. In these circumstances it is all the more important that every effort should be made not to introduce complications unnecessarily, and that the computer itself should not impose them.

The temptation to embark on additional complications is large; the thought that one extra complication will not matter among so many, and a natural pride in being clever, are constant arguments. It is always possible to achieve some gain in other respects at the expense of simplicity. Thus optimum programming will undoubtedly give an increase in computing speed, but the loss in simplicity—and in flexibility—is serious;

a complex order-code will in some cases give a similar increase; facilities for addressing magnetic-tape information may give some occasional advantages, but will certainly increase the complexity of the system. Every additional facility must of course mean some loss in simplicity but, in considering the facilities provided, a constant review must be made of this point, for it is only too easy to reach a point at which the loss more than outweighs the gain.

2.2 *A Computer for Production Control*

The characteristics which have been considered in the foregoing are of significance in any computer to be used for commercial work. However, it is now proposed to consider their relevance in the field of production control.

The first point that must be made is that this field is so wide that the requirements of two applications may be very different. The two applications reviewed in sections 3 and 4 are a very good illustration of this point. However, even where the first application is of limited scope, and covers only part of the field, some regard must be paid to the whole field, since it is unlikely that the eventual application will conform to the initial limitations.

As regards the general field, it must first be recognized that it is a non-mathematical application. While linear-programming techniques are undoubtedly applicable to certain aspects of the work, it seems unwise to regard them as more than possible future refinements to a basic system which must first be made to function reasonably effectively. In all but a few special cases, the need for a significant amount of human intervention and human decision makes it difficult and unwise to attempt to make the data processing fully automatic. In any event, one of the prime requisites of a system which has such a wide impact is that it should win and keep the confidence of all who are concerned with it, and it is essential, therefore, that the processes should be simple and capable of ready understanding. Thus, although large amounts of data require to be dealt with, the processes are not, in general, sophisticated. In consequence, although the computing speed must be high, this factor must not be over-emphasized.

In certain parts of a production control job, significantly large amounts of information are interrelated, and may require to be ranged over during the course of processing. This applies particularly to those parts where shop, machine group, or individual machine loading are involved; it may well be necessary to deploy work over a large number of machines or groups, and over a number of time periods. In such instances a considerable storage capacity may be highly desirable; but, on the other hand, it must be remembered that some parts of this storage, if provided, will be relatively little used.

Storage speed will be found to be of considerable influence; the size of the immediate-access store will directly affect the general computing speed of the installation in any case, but, in such parts of the job as machine loading, the access time to the main store may comprise one of the main factors governing overall operating speed.

It is throughout the job essential, for the time being, that adequate magnetic-tape storage of good operating speed should be available. Practically every aspect of the job is characterized by the need to store and process large amounts of information, and with low-performance tapes the job must suffer.

As regards flexibility and simplicity, little can be said except to recognize that these characteristics are vital to any system, and to production control as much as any other. In fact, the demand for flexibility is perhaps higher here than in most other fields, since it is the production field that is always most subject to change and development, and the application of a computer to it will probably lead to radical changes in production programme planning methods, and the manner in which the methods are made effective.

2.3 *The EMIDEC* 1100

The following two studies which are now to be considered have been based on the use of the EMIDEC 1100 computer, and it is therefore appropriate to give some details of this machine, particularly in relation to the basic characteristics already considered.

The EMIDEC 1100 (an outline diagram of which is shown in Fig. 1) was designed for application to commercial work rather than mathematical work, and for as wide a range of commercial work as possible. The machine operates in the binary mode with a fixed word length of 36 binary digits. It is of the two-address type and automatic conversion to and from binary is provided.

EMIDEC 1100 has three main means of storing data. The first is a 1,024-word immediate-access store of magnetic cores interlaced to form a matrix which provides a range of accumulating registers and holds the computer program currently in use. Magnetic drums of 8,192 or 16,384 words provide the main internal store. Any number of drums within reasonable limits may be fitted. The third form of storage is provided by means of high-speed magnetic tape, with a storage capacity of over 13 million binary digits or $2\frac{1}{2}$ million alphanumerical characters, and a read/write rate of 20,000 characters per second. Input can be from punched cards or punched paper tape; output is via line printer, typewriter, card punch or paper tape punch. Up to 16 peripheral units (including magnetic-tape decks) may be coupled direct to the computer.

To give some indication of speed of operation, addition and subtraction take 125 microseconds, while multiplication and division are accomplished in 1,120 microseconds.

2.4 *Introduction to Parts* 3 *and* 4*: The Approach to Material and Production Control*

The organizational structure of a company depends on the personalities and abilities of the people involved, in spite of charts which sometimes attempt to prove otherwise, and the application of a computer to production control must always be made in accordance with the real executive framework which is established. The production control procedure of which the computer forms a part, must, in any case, be the best that can be devised. It must be designed so that the activities of each of its portions conforms with its total activities. If this mutual agreement does not exist, then the end result is not orderly and meaningful but a jumble of semi-independent processes. In each application the effectiveness of the computer is limited by the quality of the data fed to it and the manner in which the results are used.

Electronic data-processing for production control can be approached in a number of ways. The production control system can be regarded as a "whole" from initiation of sales forecast to completion of the finished product, or it can be looked upon as a series of discrete yet interrelated processes which come together with associated sales, engineering and financial functions to form the "whole" of the manufacturing organization. The authors have chosen systems studies to illustrate the different approaches mentioned.

3 A SYSTEM OF MATERIAL CONTROL

3.1 *Material Control and Accounting*

The first of these studies concerns a proposed system of material control and accounting in a group of companies in the electrical industry. The organization incorporates a number of manufacturing companies which operate on both the batch and order production systems, yielding materials which are dealt with in three main ways. There is the material purchased for specific customer orders and costed on this basis; materials for use in one or more products for which sales are anticipated and which are purchased and controlled against a comprehensive production programme; and general direct and indirect materials purchased and maintained against pre-set maximum/minimum levels.

The computer will be required to analyse the products into their constituent components, to record and control the appropriate materials through various phases of production, and to perform the cost accounting routines associated with these operations.

3.1.1 *Organization*

The principal material control records such as parts lists, material stocks and job records will be maintained on magnetic tape. Input data will be carried in one of two ways, as appropriate. Those from outside sources, for example the planning or purchasing sections, will be punched into paper tape, whilst those emanating as carry-forward information from previous computer runs will be on magnetic tape. Information destined for further manual processing will be printed in tabular form, whilst data for use at a later stage by the computer will be on magnetic tape. When information is received from outside sources it will be sorted in the computer section and fed to the machine in parallel with data previously recorded on magnetic tape. Inside the machine various operations will be performed and new tapes or tabulations produced as required.

In systems such as the one being described, no visible records are maintained but reasonable access to the magnetic-tape records is allowed by means of interrogation procedures at suitable stages. A flow chart of the scheme is shown in Fig. 2 (see p. 32).

3.1.2 *Material Control Records*

The bulk of the responsibility for requisitioning material is vested in the computer on the authority of two main material-control records kept on magnetic tape. The first of these—the Parts List tape—represents in digital form the piece parts, sub-assemblies and assemblies, together with the relationship existing between them in the product manufactured. The second main record is the Parts and Primary Materials tape and carries details of primary material, factory-finished and bought-out stock balances, together with on-order and in-progress totals. Details are also carried of work being performed by sub-contractors. Most of the work associated with any Parts List tape is in its compilation, the work required to maintain it being, by comparison, quite small. The production and up-dating of such tapes depends on a sound manual system for originating parts lists, alteration notes, and similar information.

The bulk of the clerical effort connected with material-control records on a manual basis is with respect to the posting of stock transactions. It was of particular importance in the development of the computer-assisted scheme being outlined that the posting of stock transactions be made as automatic as possible. Most of the postings stem directly or indirectly from analyses of the Parts List tape. Direct postings occur as a result of purchasing requisitions or orders being placed, indirect as a result of goods being received or issued. A substantial proportion of the postings are in fact made automatically by the computer from calculations performed within itself. Others, such as the receipt and issue of most materials, are effected through the use of pre-printed stationery, leaving only a small proportion of hand-written documents, such as scrap notes and casual issues, to be processed in addition. Information stemming from manual sources is laid out in a simple and standard manner. In addition to the main material control records other records are, for the convenience of data processing, maintained on magnetic tape. These relate to the "bonding" of materials to specific jobs or contracts.

3.1.3 *Accounting Records*

The principal records for material accounting are also held on magnetic tape. These records are up-dated by information such as suppliers invoices fed to the computer on punched paper tape, and from data produced in other computer operations recorded automatically on magnetic tape. A record is established for all materials identified as to production or other requirements so that charges and costs may be apportioned. Two main

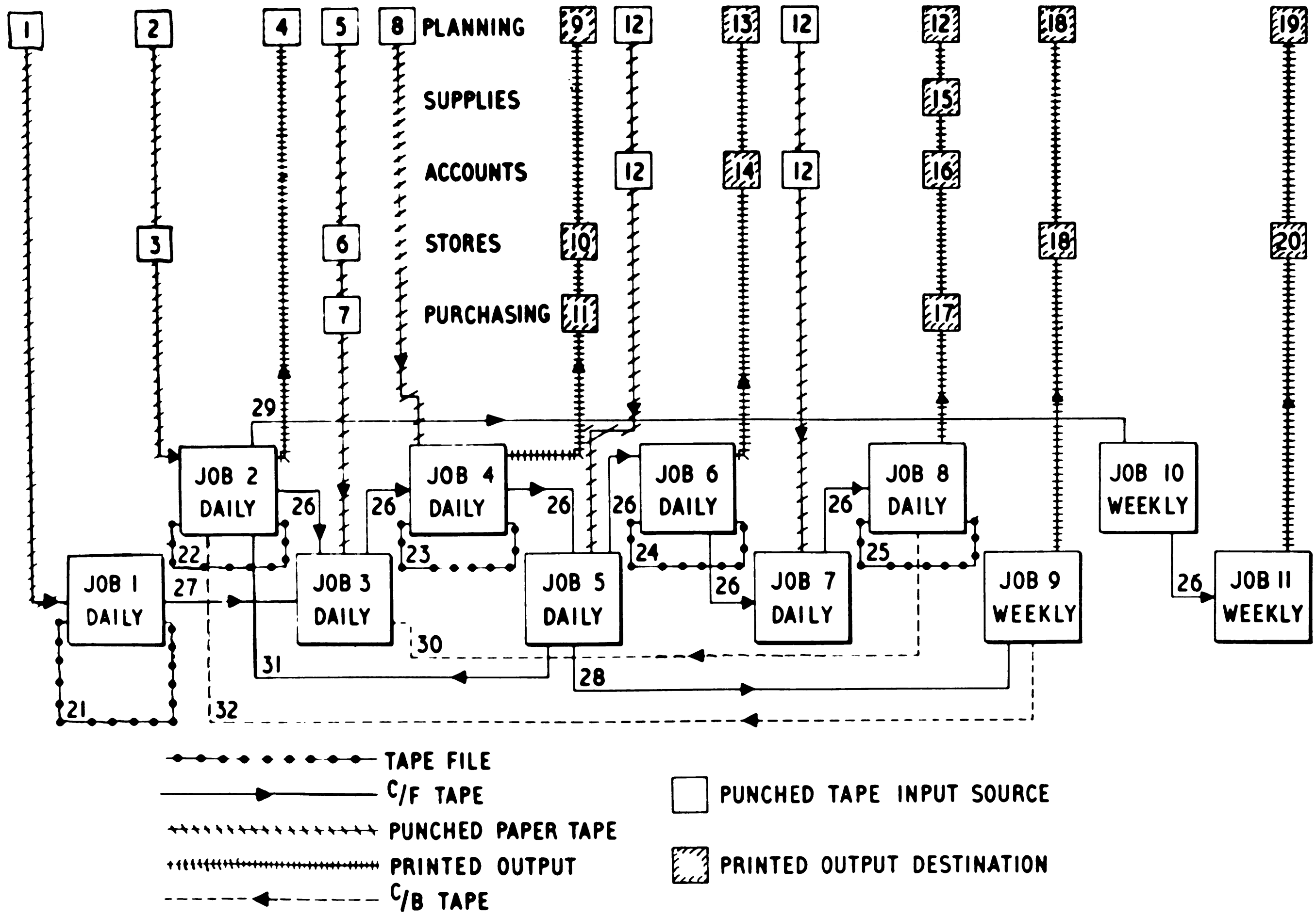

Fig. 2.—Flow chart for material control on a computer.

Key to Fig. 2

1. New parts lists; modifications; interrogations; authorities to manufacture; assembly authorizations.
2. Cancelled feed notes.
3. Planned issues.
4. Overdue feed notes.
5. Authority to machine; interrogations; new parts data; other material requirements; scrap notes.
6. Supplementary feed notes; goods received notes; final operation completions; indirect and emergency issues; returns to suppliers; returns to stores.
7. Orders on suppliers.
8. Cancelled allocations.
9. Primary feed notes; stores transfers.
10. Parts to be made; cancellations; provisional allocations.
11. Material requisitions
12. Interrogations.
13. Interrogations; key materials.
14. Interrogations; material costs.
15. Delivery schedules.
16. Remittance advices; discrepancies; commitments; reconciliations; interrogations.
17. Urge advices; overdue deliveries; receipts and invoice discrepancies
18. Assembly feed notes.
19. Stores transfers.
20. Stores transfers.
21. Parts list tape.
22. Bondings record tape.
23. Parts and primary materials tape.
24. Job record.
25. Suppliers record.
26. Current data.
27. Gross requirements.
28. Assembly bondings.
29. Stores transfers.
30. Direct charges and variances.
31. Primary material bondings.
32. Assembly bondings.

accounting tapes are established: the Job Record and the Suppliers Record. The first bears all materials costs accounting data for production jobs and indirect expenditure headings; the second is a combined record of suppliers identity and reference data, outstanding order information, and the purchase ledger. Additional accounting data is set up on magnetic tape and mainly concerns direct charges and purchasing variances from standard to be fed back as appropriate to augment the main records.

3.2 *Data Processing*

The proposed scheme results in a series of integrated computer tasks, the following being a brief outline of the salient data-processing operations performed at daily, weekly and monthly intervals.

3.2.1 *Daily Operations*

3.2.1.1 *Product Analysis.*—The first of the series of daily data-processing jobs concerns the maintenance of the parts list record, and the analysis of future orders actual or potential. Details of amendments to the Parts List tape are fed to the computer on paper tape, and the magnetic tape file amended accordingly.

There are two points of particular importance, the first concerning classification and coding, and the second design alterations. The smooth introduction of a computer-aided system of material control depends in part on a fully effective coding scheme for products, assemblies, factory-made and purchased parts, and primary materials being available and tested. Of equal importance is the efficient functioning of a design alteration system. It is necessary that full disposal instructions and dates be carried on all alteration notes so that any new parts lists or stock records created may run in parallel with the old as required. Analyses of products are made on receipt of suitable authority, and a magnetic tape containing gross material requirements will be produced.

3.2.1.2 *Materials and Cost Recording.*—The second of the main daily data-processing jobs maintains materials balances and records the distribution of material between the group's products. Details of new orders placed, and materials received and issued, together with the gross requirements already mentioned, are fed to the computer, new balances are struck, and material balances and requisitions produced for use by the purchasing division. Details of invoices are compared with deliveries and costs apportioned as appropriate.

From automatic reference to the magnetic tape, data are printed urging the placing of orders by the buyers and for the use of the buyers in urging deliveries from suppliers. Information is produced for use by the planning sections, such as lists of parts to be made against new manufacturing plans, and details of key materials likely to regulate production. Finally, sundry variance tabulations are produced, such as invoiced quantities against deliveries actually made, and price variations from prices negotiated or from established price standards.

3.2.2 *Weekly Operations*

From data contained on the Parts List tape and the Parts and Primary Materials tape, the computer each week translates the assembly schedule into bills of material to be issued. These bills, which are in part-number order within assembly-number order, list not only the quantities to be issued but, as required, the location of the stores to which the materials are to be transported for marshalling and issue when called for. In a somewhat similar manner, each week, principally from reference to the Parts and Primary Materials tape, the computer produces material-feed notes for batches of parts authorized by the planning department to be manufactured.

In both the case of assembly bills and primary material-feed notes, automatic reference is made to stock records and, in the event of stock not being available, information is supplied for the requisite progress action to be taken to achieve continuity of production. Material costs statements are also produced weekly.

As a result of the foregoing operations, the Job Record tape will be brought up-to-date.

3.2.3 *Monthly Operations*

There are two main monthly cycles of operation:

1. Remittance advices.
2. Suppliers delivery schedules.

With regard to remittance advices, it has already been mentioned that invoice details are compared with material deliveries. All invoices passed for payment are posted daily to the "purchase ledger" on the Suppliers Record tape for the monthly printing of remittance advice notes and traders credit slips. Cheques, as required, are produced manually.

The other main monthly job is the calculation and printing of suppliers delivery schedules. These schedules are in part-number or primary materials-number order within supplier-number order, in the form of a fixed schedule for a given period of a month, followed by a tentative schedule for a further period. Experience has shown the monthly rotation of schedules to be a suitable one. Faster rotation means the processing of much larger quantities of data to very little enhanced effect; slower rotation leads to inaccuracies between deliveries and unavoidable changes in production programmes.

3.2.4 *Other Operations*

In addition to the principal data-processing operations performed at daily, weekly and monthly intervals, more occasional tasks likely to prove of service are included. For example, details of slow-moving stocks are printed at six-monthly intervals, and redundant or surplus material lists are raised as appropriate. It is, of course, stressed that these and other statistics are only produced if a genuine need for them is proved.

4 A SYSTEM OF PRODUCTION CONTROL

4.1 *General Outline*

It is now proposed to describe another system based on a study recently carried out over the whole field of production control for a large manufacturer in the engineering industry. The system outlined above dealt with the material control aspects of production control and these will not be discussed in connection with the study now to be described. The importance of material control is not minimized, however, and was fully allowed for in the following system.

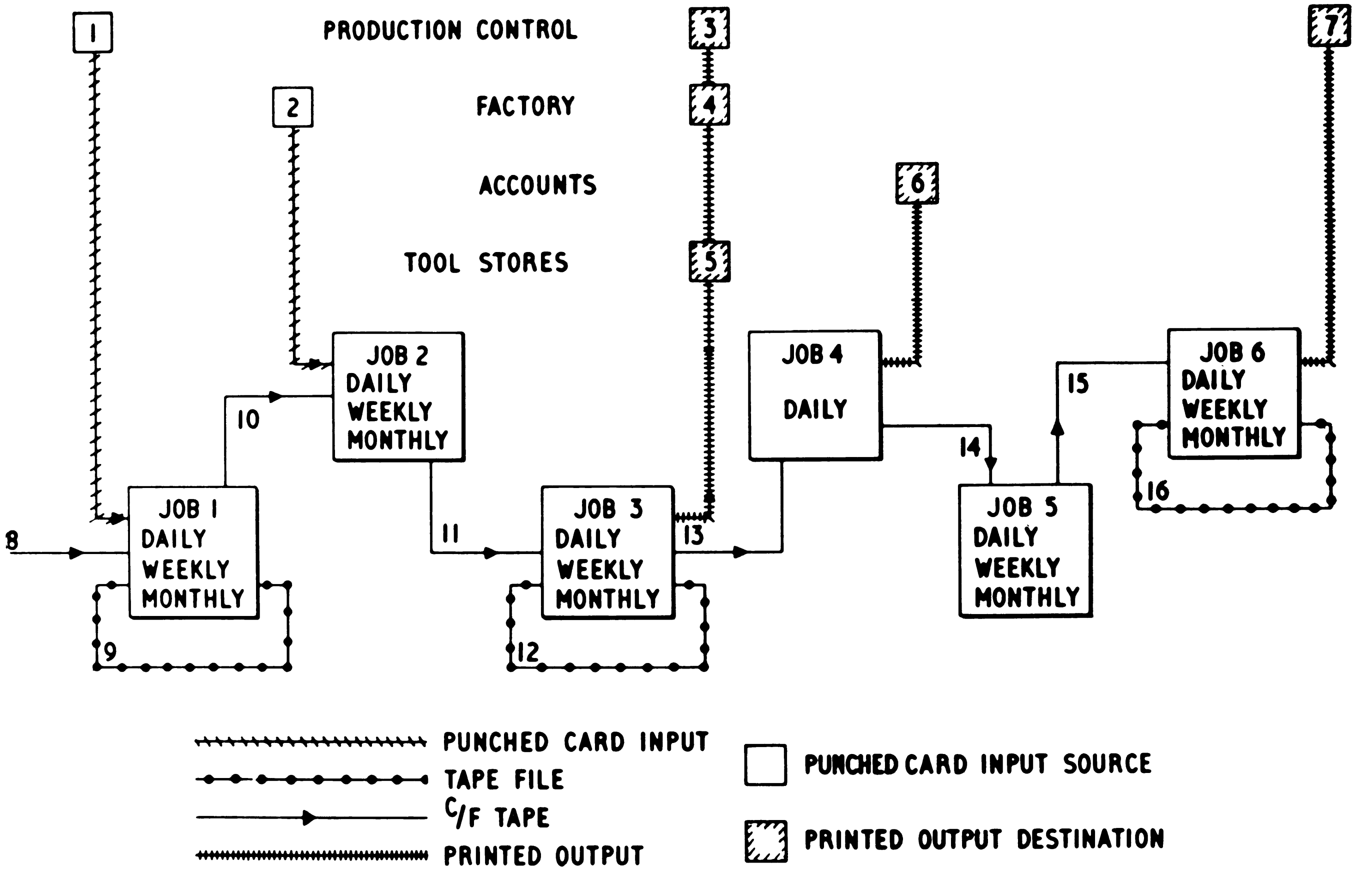

FIG. 3.—Flow chart for production control on a computer.

Now, however, emphasis will be placed on those aspects of production control which have so far not been discussed in computer terms: plant loading, work scheduling, and the monitoring of production programmes. The approach is a simple one and the three things regarded as important for effective loading and scheduling are:

1. Time-in-progress as a minimum.
2. Queuing before machines as a minimum.
3. Plant utilization as a maximum.

4.1.1 *Organization*

The organization for this proposed computer system is similar to that outlined in 3.1.1 in that the main records are carried on magnetic tape. Carry-forward and input data are on magnetic tape or punched cards.

4.1.2 *Magnetic-Tape Records*

There are three main magnetic-tape records termed, respectively, the Product Data file, the Scheduled Orders file and the Loading Schedule. The first of these carries details of all processing operations performed on factory manufactured parts and records of associated tooling equipment. Information is carried of set-up times, processing times, standard intervals between operations, together with the time at which the item is required in advance of final assembly or key sub-assembly, and the economic processing batch size. The second tape records details of every order to manufacture a product which has been scheduled on the plant. Orders are normally scheduled separately, since there is seldom great similarity of order details, or of production phases for successive runs of the same product. The third tape carries details of plant capacity by machine type.

Key to Fig. 3

1. Modifications to schedule; interrogations.
2. Operations completed.
3. Key processing outside limits; progress data; loading schedule.
4. Processing schedule; assembly schedule.
5. Tool requirements.
6. Operations completed.
7. Reports on scheduled orders.
8. Stock availability data; authorities to manufacture.
9. Product data file.
10, 11. Carry-forward data.
12. Loading schedule tape.
13, 14, 15. Carry-forward data.
16. Scheduled orders tape.

4.2 *Data Processing*

As in the scheme outlined in Part 3, the present system results in a series of integrated data-processing tasks performed at daily, weekly and monthly intervals. Fig. 3 shows the computer organization.

4.2.1 *Daily Operations*

Ignoring the maintenance of the magnetic tapes for such things as new plant received or machine tools going out of commission permanently or temporarily, the main daily tasks concern the scheduling of new orders, and the re-scheduling and monitoring of existing orders.

4.2.1.1 *Initial Scheduling*.—The initial scheduling procedure corresponds to the "key" processing system mentioned in 1.2, and its purpose is to test and, if available, reserve critical processing capacity. It is necessary that the punched-card input carries suitably coded "limits," so that key processing is either reserved against a required time schedule or rejected as being outside the limits set. If the latter applies, printed output is prepared for management attention. Details of orders initially scheduled are posted on the Scheduled Orders file.

4.2.1.2 *Monitoring of the Production Programme*.—Before any final scheduling can take place it is axiomatic that an up-to-date assessment of factory capacity and current performance be available. In the present proposed application a document is issued for each machining or allied operation performed on each batch of work issued. This document or "work ticket" is printed by the computer on a weekly basis, as will be discussed later, a magnetic tape bearing the same information being produced simultaneously. When tickets are returned to the computer section, on completion of processing operations, a minimum of information is punched, into cards, for the subsequent augmentation of the magnetic-tape records. Following these operations, vital data may be printed for the acceleration of work tending to fall behind schedule and the deceleration of operations tending to get in advance.

4.2.2 *Weekly Operations*

4.2.2.1 *Process Loading*.—The final scheduling of work on the manufacturing—as distinct from assembly—departments is done on a weekly basis. Whilst each machine tool is loaded separately during the computing operations, the final printed schedule relates to groups of plant only, and permits the shop supervision to have limited flexibility in assigning individual operators and machines to various batches of work. Two codes are introduced during detailed scheduling; one converts allowed times to actual times on the basis of previous group performance, and the other grades operations to plant according as the latter's capacity is standard, limited (possibly by reason of age), or extended (as when a lathe bed is modified to give additional swing). These factors have been mentioned elsewhere (Kease, 1957 *a*, *b*).

The loading of individual machines prevents residual capacity on groups of machines being regarded as necessarily available for production work, whilst at the same time permitting a certain amount of automatic scheduling of operations on alternative plant, as, for instance, where work specified for performance on one size of chuck capstan may be loaded onto a larger size lathe. A simple code may be developed permitting unconditional loading onto larger capacity machines within groups, and conditional loading onto smaller capacity items of plant.

The scheduling of first operations uses data, produced in previous computer tasks, as to the availability of material. The scheduling of second and subsequent operations takes into account the completion—or probable completion—of previous processing operations. During the weekly scheduling tasks, work tickets for each operation are produced, due regard being given to the data on batches and times mentioned in 1.3.1. Notification of equipment requirements is also printed to enable the tool stores to prepare jigs, fixtures, gauges, and cutting tools for issue. The issue of primary material is dealt with in a similar manner to that discussed in 3.2.2.

4.2.2.2 *Assembly Loading*.—Since the operations performed on the assembly sections are mainly manual, the "scheduling" on these departments is based on an assessment of capacity from previous performance figures, the computer producing feed lists to enable the material to be marshalled as required. Details of a similar marshalling system in conjunction with an EMIDEC 1100 procedure have already appeared (Kease, 1958).

4.2.3 *Monthly Operations*

The main loading sequences are done on a monthly basis and cover a period of three months ahead of the computing date. The results of the initial scheduling procedure with regard to key processing operations within this period are naturally taken into account, and are regarded as final so far as definitely authorized production requirements are concerned. It has been stated recently (Bryen, 1958) that, whilst an optimized sequence of manufacture over the whole of the production programme is desirable, it is probable that the mathematical tasks of establishing this optimum for even a moderately sized factory is beyond the scope of any existing computer in the time allowable for such computation. This has been recognized; a compromise solution is in fact resorted to in the present case, the first element of which is the finalizing of the key sequences already mentioned. The second important element is the *a priori* establishment of precedence among the various orders for products which require to be executed.

From a carry-forward tape bearing details of net manufacturing requirements, and the Product Data file, the computer establishes the operational requirements by plant type, and these are recorded on magnetic tape. This last-mentioned tape is then run in conjunction with Loading the Schedule tape, and a preliminary computing sequence establishes likely over/under-load conditions, and printed output is prepared for management to consider local sub-contracting, regular overtime working, or the issuing of work ahead of normal schedules to fill under-loaded periods.

When these decisions have been made, the appropriate data are punched into cards and the main loading run commences. The codes and inhibitors mentioned are used, and the computer loads each piece-part contained in each production order, commencing with the last operation to be performed on each, since, as reference to the diagram in the Appendix will show, the relationships between end-dates as planned are the only recognizable data available.

This load schedule is the one on which the delivery schedule is ultimately based and from which the Scheduled Orders file is maintained. It is also, of course, the load schedule which acts as a basis for the weekly scheduling sequences and the production of work tickets.

Auxiliary functions are also performed on a monthly basis; these, in particular, relate to the production of plant utilization figures to be used by management in attempting to assess factory efficiency.

5 CONCLUSION

5.1 *General Conclusion*

It will be apparent that the study of the application of a computer to production control is a fascinating one. It is also, generally speaking, in its infancy. Industry is becoming increasingly complex and the use of computers, whilst possibly initially adding to the complexity, should ultimately, from the production control aspect at any rate, increase our understanding of our factories as manufacturing entities, and lead to the more effective utilization of our productive resources.

5.2 *Acknowledgements*

The authors wish to thank the Directors of E.M.I. Electronics Ltd. for permission to publish this paper, and also Mr. N. D. Hill, Manager of the Computer Division of that Company, for his continued guidance and encouragement.

REFERENCES

BRYEN, J. F. A. (1958). "Digital Computers in the Factory," *Control*, Vol. 1, p. 216.

KEASE, W. J. (1957 *a*). "The First Computer Production Control?" *Metalworking Production*, 24th July 1957, p. 1148.

KEASE, W. J. (1957 *b*). "Computer-assisted Production Control," *Journal of Institution of Production Engineers*, July 1957, p. 423.

KEASE, W. J. (1958). "Computers and Materials Handling," *Mechanical Handling*, Vol. 45, p. 784.

APPENDIX

In Part 1 it was stated that whatever system of production exists, assessments of available plant capacity and materials requirements have to be made, if an overall production plan is to be effectively formulated. It was also indicated that such assessments can only be made on the basis of recorded data, and six items were left in section 1.3.1 (p. 25).

It is now proposed to show how these data must operate with respect to material control within the framework of a batch production situation, the order production situation having been dealt with sufficiently in Part 1. Whilst the context is imaginary, the assumed values of the data are realistic and the operations are based on experience.

It is suggested that the diagram, Fig. 4, be referred to throughout the following explanation.

Stage 1

It is assumed that it is desired to manufacture two types of article, Product *A* and Product *B*. Both products contain a number of materials all of which progress, in their transformation to a finished saleable state, through a number of main processing and assembly operations. Both products incorporate the piece part *a*, on which, for simplicity, all subsequent stages of the diagram are based.

Product *A* requires 5 off *a* at an early point of production, and 2 off *a* at a later point. Product *B* contains 4 off *a* at one point only. Previous analyses of key data have shown that Product *A* can be finally assembled at a rate of 50 per two weeks for six weeks, and Product *B* at a rate of 20 per week for four weeks commencing 3 weeks before Product *A*. The production schedule is, therefore, of 8 weeks' duration. It is known that the processing time for *a* under production conditions is 4 weeks, that the minimum lead time for the earlier requirement of *a* in *A* is 9 weeks, and for the later is 3 weeks. The minimum lead time of *a* in *B* is 6 weeks, and the material minimum ordering period is 10 weeks. A representation of these data in standard Gantt chart form is shown in Stage 1 of the diagram.

Stage 2

It is now possible to calculate the gross material requirement of *a* against the time base. This results, for Product *A*, in:

250 — 250 — 250 — 100 — 100 — 100

and for Product *B* in:

80 80 80 80 — — — — — — —

representing requirements schedules as mentioned in 1.4, and spread over 11 weeks.

It is assumed that there are 5 finished piece parts *a* available, enabling the first quantity in schedule *A* to be reduced to 245, there being no raw material already available. The total requirements of raw piece parts *a* to be purchased is therefore 1,365.

Stage 3

It was indicated in Part 1 that orders for materials are usually placed on the basis of the requirements schedules, which act as the basis for negotiations with suppliers and, after allowance has been made for delivery

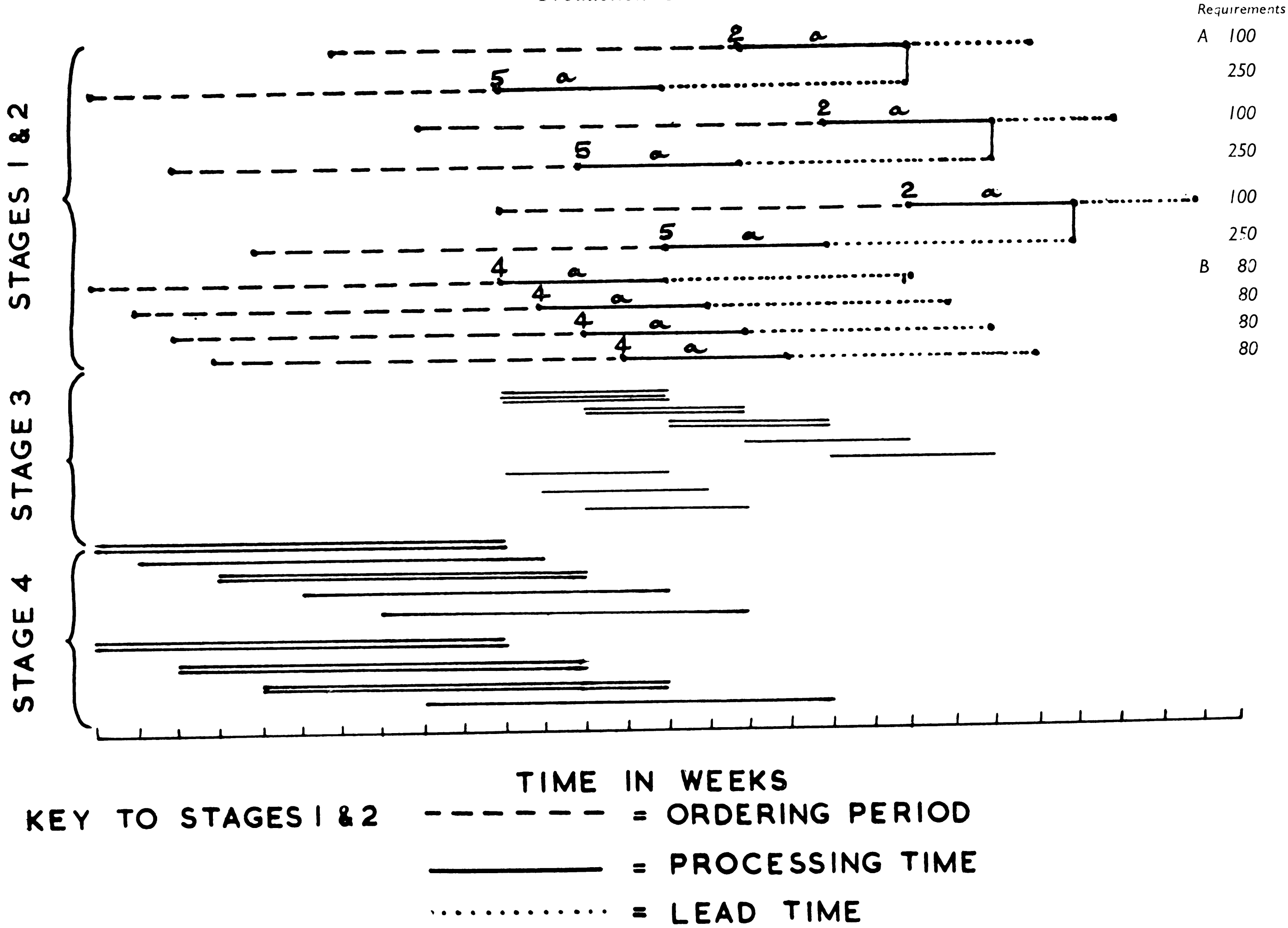

FIG. 4.—Gantt chart showing relationship between production phases.

periods, set reasonable limits to the dates on which deliveries begin and end. In practice, the actual schedule against which material is delivered probably differs from the requirements schedule by virtue of economic batch criteria, plant capacity, or the need to split orders between two or more suppliers.

In the imaginary situation being discussed, it is assumed that the piece parts *a* are processed in two separate factory locations, and that the minimum economic processing batch size is 100. The processing schedule for the piece parts *a* is as follows:

Location 1.	100 × 3	—	100 × 2	—	100 × 3	—	100 × 1	—	145 × 1
Location 2.	100 × 1	100 × 1	120 × 1	—	—	—	—	—	—

The schedule is spread over nine weeks.

Three multiple batches have been issued, and two batches of sizes larger than the minimum but smaller than multiples. It will be noticed that the number of plant set-ups is 8 compared with 10 separate requirements of *a* in *A* and *B*.

Stage 4

From the processing schedule, the suppliers' delivery schedule can now be calculated. The material ordering period is 10 weeks, and orders are placed on two suppliers, 700 of *a* on Supplier 1 and 665 of *a* on Supplier 2.

It is assumed that the minimum economic purchasing batch size is 100 and that, on a weekly delivery cycle basis, up to two batches can be delivered by each supplier. The material delivery schedule can, therefore, be as follows:

Supplier 1.	100 × 2	100 × 1	—	100 × 2	—	100 × 1	100 × 1
Supplier 2.	100 × 2	—	100 × 2	—	100 × 2	—	65 × 1*

General Note on Stages 1–4

Under production conditions it would most probably be known if the production schedule was likely to extend beyond the 8 weeks shown or if the piece part *a* was likely to be absorbed on other future production. If one or both of these situations could arise then material for 1,400 *a* piece parts could be ordered (the purchasing

* The last batch on Supplier 2 would be the subject of special negotiation.

and delivery conditions being obviously available), 700 from Supplier 1 and 700 from Supplier 2.

In these circumstances, the processing schedule for location 2 would remain as outlined, but the schedule for location 1 would end with a large batch of 180. The material delivery schedule would read:

No special negotiations would take place with Supplier 2 and there would be 35 piece parts *a* available for the next production requirement.

Supplier 1.	100×2	100×1	—	100×2	—	100×1	—	100×1	—
Supplier 2.	100×2	—	100×2	100×2	—	—	—	—	100×1

SUMMARY OF DISCUSSION

The following points were made during the discussion which followed the presentation of the above paper to The British Computer Society in London on 19th January 1959.

Mr. C. Haynes (*Kodak Ltd.*): The authors have referred to the main loading sequences as being done on a monthly basis: having regard for the weekly scheduling of work on the manufacturing departments, would not a weekly basis be better also for the main loading sequences?

Mr. C. P. H. Marks (*Ministry of Supply, A.G.* 45): The schemes described by the authors for processing information for production control were impressive. It seems, however, that they would require an enormous input of (*a*) planning data, (*b*) feed-back data regarding performance, from the shop floor. In practice, it is exceedingly difficult and very expensive to obtain the origination of complete and accurate data, and to communicate them to the computer in a form suitable for processing. Has this problem been studied and what are the authors' views?

Mr. H. N. Buckland (*British Tabulating Machine Co. Ltd.*): Would the authors be good enough to explain whether they envisage issuing an ordering schedule for planning department to issue orders, or whether the computer would print out all documentation, and if so, what form would it take?

The method of loading described by Mr. Kease was for the last operation of an order to be loaded first and then to load backwards for all subsequent operations. If two orders were required to be completed in the same week, what method is proposed to ensure that the order with the greater number of hours work-content and operations is loaded first?

Mr. Francis Bryen (*British Tabulating Machine Co. Ltd.*): The authors have referred to a method of selecting certain key items in terms of machine-tool capacity and raw material availability. Have their thoughts in this direction been developed to the extent that the theory involved can be applied to a practical application, involving perhaps 100 different types of machine-tool equipment within a factory and perhaps 25,000 different machined components?

Mr. F. W. Jarrett (*Standard Telephones and Cables Ltd.*): Is it proposed that one-off jobs should be dealt with under the mechanized production-control routine, bearing in mind the expense involved?

The authors (*in reply*): The weekly scheduling of work on the production departments should, ideally, be merely a confirmation of a load previously established on a monthly basis. The computation of the monthly loading sequences is undertaken to enable capacity to be rationalized well in advance of production dates, and material delivery schedules to be finalized. Experience has shown that suppliers will not accept weekly delivery schedules.

Whilst allowing the importance of Mr. Marks's question, it must be pointed out that without data any form of production control is impossible. It is true that, to be effective, the computer demands a large volume of planning and progress data. The accuracy of these may be best achieved by spending a lot of time and money on getting basic information such as parts lists well established; continuous data should be printed wherever possible and cross checks applied throughout the whole of the data-processing procedure.

In reply to Mr. Buckland it is proposed to print out all work tickets and the like by way of the computer printer. A simple code may be developed to ensure that high-priority work is loaded first. The "operation number" itself is a guide to the number of operations involved, and to this may be added an indication of throughput time. The combined symbols could then designate the particular part's importance in the planned production schedule.

The author to whom Mr. Bryen's question was specifically addressed is aware of the importance of this point, bearing in mind the superb pioneer work being done by Mr. Bryen and his staff. It is always difficult to decide where "key" data and "normal" data divide. The theory as such could apply to a factory of any size, on work of any complexity, provided that the "key" level was not set so low as to permit the schedule to become saturated, and hence meaningless, so far as this aspect of production control is concerned.

Mr. Jarrett has raised a question often heard at discussions on production control. The expense involved in obtaining data for one-off jobs, whether by means of synthetics or even guesses, must be weighed against the value of the control desired to be achieved.